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Agricultural Science and Improved Human Nutrition

By WILLIAM H. ADOLPH, Ph.D.*

Introduction

When early man became agricultural, he turned to plants and plant products to supplement or even replace meat as food. The history of nutrition over the last few thousand years is largely concerned with his attempt to do this effectively.

Many plant foods, however, are deficient in important nutrients and this has prompted attempts to employ agricultural methods to improve their nutritive quality. It would be rather convenient for example if a calcium deficiency in the human diet could be met by appropriate addition of calcium fertilizer or by other adjustment in the soil environment. In this review, we will discuss the results of some of the investigations in this field.

Much of the agronomist's interest has been directed toward increased crop yields, that is, more food and more calories. This review however is primarily concerned with qualitative changes in the agricultural product which may enhance its nutritive value, and favorably affect the nutritional status of population groups. The fact that the farmer has in the past been preoccupied with total production may account for the fact that fewer experiments have been undertaken where the goal is optimum nutritive value.

"Worn-out" Soils

Popular comment, referring to 'worn-out' soil, often insists that the inferior quality of diets in underdeveloped countries is related to soils which have become 'exhausted' by many centuries of cultivation. Experience does show that exhausted soils may produce smaller yields, but there is still lacking evidence to support the belief such soils produce food materials of lowered nutritive value when fed to humans. There is much evidence that the plant maintains a remarkable constancy of composition over many generations even on unfertilized soil.

If worn-out soils are thought to yield plant food of inferior nutritive value, it should be possible to show that corrective measures applied to the soil, namely fertilizer, can result in improvement — that is, qualitative improvement measured in terms of human nutrition. So far there is but one generally acknowledged case of a relationship between the soil environment and human nutritional status — that between iodine deficiency and endemic goiter. There is evidence of

*Lecturer in Nutrition, Yale Nutrition Laboratory
Yale University, New Haven, Connecticut

malnutrition among ruminant animals in areas where the soil is deficient in phosphorus and in some of the trace elements, and this would seem to lend credence to the 'exhausted soil' hypothesis. There is however no evidence except in the case of iodine, that human populations inhabiting such areas are similarly affected.

Experimental Approach

To set up an experiment testing the relationship between the agricultural factor and nutritional health in man would be almost impossible. It would be extremely difficult to arrange the necessary controls for a long-term experiment with human subjects.

Instead, less complicated experiments have been undertaken. It is possible to investigate changes in the composition of food plants with varying factors, including soil environment. It is possible to measure the growth of animals fed plants grown on fertilized and unfertilized soil. It is also possible to study the behavior of milk-producing and meat-producing animals on different soil-improvement and feeding regimes. Such partial approaches to the problem yield data of value.

There are three general avenues of experimental approach. An alteration in nutritive value of the plant may be related to:

(1) climatic factors, such as temperature, moisture, light intensity; *(2)* soil factors, including fertilizers; *(3)* genetic factors.

The first two of these three have been the subject of many experiments and the results have been less promising than might have been hoped for. The third, the genetic or plant breeding approach, shows unusual promise and is now being pursued with vigor.

CLIMATIC FACTORS

Many of the studies on the influence of climatic factors on the nutrient content of plants are concerned with determinations of ascorbic acid; this vitamin lends itself readily to chemical analysis. Some attention has also been given to carotene. The factors themselves — light, temperature, moisture, etc., are difficult to separate. Somers and Beeson have reviewed the results of earlier experiments in this field (42).

At the U. S. Plant, Soil and Nutrition Laboratory at Ithaca, N. Y., tomatoes were grown in sand culture under controlled conditions. Plants grown continuously in sunshine showed an ascorbic acid content of 25.8 mg. per 100 g. of fresh weight, while those grown continuously in the shade showed 15.5 mg. These changes moreover were found to be reversible. Plants grown at 25° C. contained 16 percent more ascorbic acid than those grown at 17° C. (17). In experiments with turnip greens, it was shown that the ascorbic acid content could be varied about tenfold by changing the light intensity (19). Turnip greens grown in sunshine contained less carotene that those grown in shade (43). The

influence of moisture and water supply on ascorbic acid and carotene has been studied with turnip greens, but the results indicate no significant differences in vitamin content as these factors are varied (22).

Data on the B-vitamins are less abundant. A recent series of experiments with peas, beans and tomatoes however shows that higher temperatures and longer exposure to light decrease the thiamine and increase the riboflavin and niacin content (15).

Very extensive studies undertaken by the Southern Cooperative Group over the period 1945-53 indicated large differences in the ascorbic acid, thiamine, riboflavin and carotene contents of the same varieties of vegetables grown at different locations. The ascorbic acid in one variety of lima beans for example ranged from 66 to 121 mg. per 100 g. dry weight for different localities, and the other vitamins showed similar wide ranges in amount (12). The 'location factor,' it would appear, is often of greater importance than other factors (37).

Among the climatic factors, light and perhaps temperature markedly influence the amount of vitamin produced: Findings of this sort may be of practical interest in the case of greenhouse vegetables. All such 'improvements' in vitamin content, however, are often insignificant when compared with the huge loses encountered in irregular harvesting, storage, cooking, and wasteful handling.

SOIL FACTORS (including FERTILIZER)

There is a large literature on this subject; several reviews have discussed the relationship between the soil factor and human nutrition. (3, 30, 4, 32).

Fertilizer and Vitamins

The amount of ascorbic acid and carotene produced in the plant has been employed to measure fertilizer effects. In one series of experiments on turnip greens where the soil nutrients were varied widely, the addition of potassium slightly decreased the amount of ascorbic acid formed, but at the same time variations due to location were ten or more times as great as the effect produced by fertilizer (36).

The experiments of the U. S. Plant, Soil and Nutrition Laboratory on tomatoes and turnip greens mentioned above were extended to include varying concentrations of calcium, potassium, magnesium and other inorganic nutrients. None of these treatments materially altered the ascorbic acid or carotene content of the plant. The location effect however was pronounced. Tomatoes grown from the same seed in different areas showed some differences in ascorbic acid content, but no differences were observed when the soils from these areas were brought together in the same place and the experiment repeated (18). The values for carotene in turnip greens varied widely. Any fertilizer treatment which caused chlorosis was accompanied by a decrease in carotene (5). There is some indication that the influences which increased the ascorbic acid tended to decrease the

carotene. No significant effects have been found with thiamine in plants when the inorganic elements were applied as nutrients.

It may be concluded that fertilizer effects on the vitamin content of the plant are small when compared with the effects produced by climate and other factors, so small in fact that they are of little practical importance.

Fertilizer and Mineral Nutrients

Our knowledge of the chemistry and physiology of the process by which the plant absorbs inorganic nutrients from the soil is limited, but we do know that different ions behave differently. Moreover the amount of the inorganic element available does not necessarily determine the amount which a plant will absorb. This means that generalizations are unwarranted.

Calcium has been the subject of much study, presumably because the human diet is frequently reported deficient in this element, yet the results are quite confusing and often contradictory. In one experiment with kale, for example, a marked increase in calcium content was obtained when limestone was added to the soil (21). Another experiment on kale showed practically no increase (20).

One of the most comprehensive series of experiments on fertilizer treatment is that undertaken by the Southern Cooperative Group as part of their project, "Variations in the Composition and Nutritive Value of Vegetables Grown in the South." In a study of turnip greens they report that when calcium was added to the soil as gypsum, there was a slight increase in calcium content, while treatment with nitrogen decreased the calcium content of the plant, and potassium exercised no marked effect on either calcium or phosphorus. Conditions associated with location however caused ten times more variation in calcium and phosphorus content of the turnip greens than was caused by fertilizer treatment (40).

The phosphorus content of plant foods is probably not of critical importance to the human dietary, since the diet is usually not deficient in this element. Several experiments however report a distinct phosphorus increase in the composition of the crop on application of phosphorus fertilizer (24, 29). Turnip greens showed an increase of phosphorus content as the nitrogen supply increased (41).

The iron content of some soils is low, but there is no proof that anemia in man is caused by lack of iron in the soil. Simple iron compounds added to the soil have little effect on increasing the iron content of the plant. An experiment with turnip greens showed that fertilization with nitrogen led to striking decrease in the iron content (44). No consistent effects on iron content of the plant have been observed when calcium and phosphorus were added to the soil. There is a pronounced antagonism between manganese and iron, and vegetation grown in highly manganiferous soils is often characterized by iron-chlorosis (26).

The results obtained on the addition of single mineral elements to the soil are sufficiently confusing, but when combinations of the macro-nutrients, the micro-nutrients and other soil factors are included in the variables, the situation

becomes still more complex and the results quite unpredictable. An experiment with corn, oats, and wheat indicated that the percentage of phosphorus, potassium, and nitrogen in the grain produced on untreated soil was as high or higher that that produced on treated soils (46).

A very comprehensive series of data has been obtained in an eight-year experiment at Michigan State University. Corn, soybean, wheat, oats, hay destined for use as feed for dairy cattle in a milk production project were grown on adjacent plots of fertilized and badly depleted soil of the same type. The climatic factors were thus the same for both. The harvested samples were submitted to complete analysis, including macro- and micro-mineral nutrients. No significant differences were found in the composition of the grain crop whether grown on fertilized or unfertilized soil. Only timothy hay was favorably influenced by fertilization (10).

The above series of field tests was supplemented with a greenhouse experiment in which soybeans, oats and alfalfa were grown on the depleted soil used in the above mentioned field experiment and the same soil treated with calcium and magnesium carbonate, monocalcium phosphate and potassium chloride at different levels. The analytical data included determinations of protein, phosphorus, calcium and iron. By the above fertilizer treatment some beneficial and some deleterious changes in plant composition are produced. None of the alterations in plant composition however were very striking and the results tend to confirm the finding of the field study that a completely balanced fertilizer may not appreciably change plant composition (35).

A review of the results obtained from experiments with mineral substances suggests that whatever changes in plant composition do result from the application of mineral materials to the soil are of doubtful significance (2). Moreover still lacking is proof that any of these changes are beneficial when translated into human dietary values. This field offers almost unlimited opportunity for further investigation.

Trace Elements

Among the trace elements: copper, iron, manganese, zinc, molybdenum and boron are undoubtedly necessary for the plant. The first four certainly, and also cobalt and iodine are known to be important in animal nutrition. Selenium and apparently also molybdenum are toxic to animals. There is an antagonism between copper and molybdenum which may express itself in an increased copper requirement. The subject of the trace elements and their bearing on nutrition has been recently reviewed (47).

It was observed that a deficiency in the soil with respect to certain of the trace elements often resulted in lowered animal production, and this led to the conviction that the trace elements are important in animal nutrition. The correction of these soil deficiencies has been important in the management of grazing animals in Australia and in developing the Florida everglades area (8).

Not only are there different requirement for the trace elements, but some of them are absorbed more readily than others. The plant seems to guard against an excess absorption of iron and copper. This may be a necessary safeguard, or it may be an obstacle which it is desirable to overcome.

There is still much to learn about the trace elements in animal nutrition. In some cases, as with zinc for example, the animal requirement is less than the plant requirement, which means that any plant which reaches maturity contains an adequate amount of this element when consumed by the animal. Thus the plant, and in the same way the animal also, may become a defense line in human nutrition, so that threatened deficiencies in the human diet become less probable.

Chelating Compounds

Chelating compounds, metal-binding complexes, have been proposed for use in promoting the absorption of mineral nutrients by the plant, particularly of the trace elements. In many soils iron does not readily go into solution, but the chelating agent presumably converts the iron into a more available form, forming ferric chelate in which the ferric ion is stabilized against hydrolysis. Iron chelates have been used to correct iron chlorosis in citrus trees grown on sandy soil (45).

Soil Conditioners

Soil conditioners in many cases affect the absorption of mineral nutrients by the plant. They may selectively absorb and retain specific nutrients and retard their absorption by the plant. Or the availability of a mineral element may be increased by applying a soil conditioner. In one recent experiment the addition of a soil conditioner caused a decrease in the calcium and magnesium content of the plant and an increased uptake of potassium and sodium (28). This is a new field of investigation, with interesting implications still largely unexplored.

Fertilizer and Protein

Studies on the protein formed in the plant are now being directed toward the amino acid content. The newer chromatographic and micro-biological techniques are making this possible.

There has been some success in increasing the protein content of the plant by liberal application of nitrogen-bearing fertilizer. An unusual increase is reported for a low-protein corn containing 7.8% protein which was altered to a corn containing 10.4% protein during a single season (16).

This amount of protein increase is enough to be of some importance. On the other hand, the high-protein corn has been found to contain a greater proportion of the incomplete protein zein than the low-protein corn. At the same time the lysine content of the protein was reduced from 3.0 to 2.4% in the high-protein corn, while tryptophane was reduced from 1.9 to 0.99%. The biological values of the two types of corn were measured with rats and with chicks, and the

high-protein corn invariably showed poorer growth when compared with that of the low-protein corn, growth being reckoned in gain in weight per gram of protein fed (39). If the result of such increases in the protein content of the crop is merely an increased proportion of low-value protein, then a program which looks only to the development of high-protein content in the crop may be of doubtful value.

Similar studies with wheat produced by high level fertilization show that the protein of the high-protein wheat contains a slightly smaller percentage of lysine (14). The amino acid content of crops with increased protein content produced by a process of crop selection is discussed in a later paragraph.

We are learning more about the amino acid metabolism of plants. Studies with turnip greens on the effect of the mineral elements indicate that the concentration of the amino acids in the protein is fairly constant and not easily altered. Reports in the older literature have suggested that calcium was an important influence in protein formation in plants. Examination of the amino acid content however now furnishes no evidence that calcium exercises such an effect (4).

Organic vs. Inorganic Fertilizers

Popular interest in fertilizers has raised the question: Are inorganic nutrients applied to the soil as effective as the same materials fed to the plant in organic form? Inorganic materials have been used largely in experimental cultures, and chemical fertilizers are largely of this type, while organic materials are represented by fertilizers of the compost type.

In one carefully controlled experiment to test this, beans and carrots were grown on compost and on mineral fertilizer. The harvested material showed no significant difference in carotene and ascorbic acid content (6). A slightly different type of experiment involved a biological measurement. A variety of grass was grown with and without soil; in the latter case a water culture was employed. The resulting crops grown with and without soil when fed as the sole food to guinea pigs over a 12-week period produced practically identical growth (1). Experiments of this type are of great value, but establishing satisfactory controls in all phases of the experiment is difficult. Evidence from another experiment suggested that organic matter in soil was effective in producing a higher iron content in turnip greens (44). There is probably no simple answer to this problem of organic vs. inorganic fertilizers, but it would seem that a sound economy would dictate the use of both in a well-balanced soil treatment.

Biological Measurement of Nutritive Value

It is impossible to overstress the fact that changes in chemical composition do not necessarily indicate changes in the nutritive value of the plant. Moreover nutritive content of the plant is not necessarily a measure of its availability to the animal. Final proof must be found in some experiment which will measure an animal response, that is, a biological method.

The problem of the biological assay has not yet been completely solved. The problem involves not only a choice of animal for the test, but also the problem of experimental design in evaluating variation both in growth of the plant and in the animal experiment. Moreover the animal experiment must be of long enough duration to yield results which are nutritionally significant. However, even the most refined experiments will have a meaning only as they can be translated into human nutritional needs.

Two extremely brief experiments are suggestive of the type of biological measurement which will throw light on the effect of the mineral elements. In one experiment fertilizer rich in fluorine was added to a growing crop, in another potassium iodide was added to the soil. The harvested material was then fed to laboratory rats and the rats examined in the one case for carious teeth and in the other the thyroids were weighed (27).

One of the most elaborate and best controlled, long-term experiments ever carried out to examine the effect of fertilizer on the nutritive value of crops measured in terms of its effect on animals is that outlined below. This experiment is so significant that we are discussing it at some length.

AN EXPERIMENT WITH DAIRY CATTLE

This experiment is part of a research project at Michigan State University, extending over the years 1945-55, undertaking to study the nutritive value of milk as related to soil fertility. A 210-acre farm whose soil was badly depleted was available. One portion of the farm was limed and heavily treated with fertilizer. Crops were grown: oats, corn, wheat, soybeans, and hay which were fed as the sole ration to two matched herds of dairy cattle for five years and the milk produced was fed to laboratory rats as a means of measuring its nutritive value. Careful controls were established throughout the experiment; the program is discussed in some detail (9). The object of the experiment was to measure the nutritional differences resulting from the use of fertilized and unfertilized soil. At the beginning of the experiment 13 pairs of half-sister Jersey and Holstein heifers were divided between the two groups and the milk produced by each herd over successive lactations for three generations was comprised in the study. During the experiment none of the cows or calves had access to any feed other than that grown on the fertilized or unfertilized plots, nor did they have access to soil or pasture.

Complete analyses were carried out on the feed crops. No attention however was given to total crop yields since this was outside the scope of the study. Records included growth curves for the heifers, blood analyses for the lactating cows, milk production data, etc. for a total of 81 lactations by 35 cows in the two groups. The milk from each cow was analyzed and the amino acid composition also determined.

The milk obtained from each cow about two months after calving was fed ad libitum to groups of male weanling rats (6 rats per group) for six weeks. The

nutritional efficiencies of the milk produced from the fertilized and unfertilized areas were expressed in gain in weight of the rat per gram of protein ingested. All data were treated statistically. It may be noted that the experiment deals with the production of feed which was fed to ruminants and with the product milk whose nutritive value was then estimated by being fed to non-ruminants. The experiment is of course an experiment in ruminant nutrition.

The results of the experiment are to found in (1) the nutritive content of the feed grown on the fertilized and unfertilized land, (2) the health and growth of the two groups of cows, (3) the nutrient content of the milk produced, and (4) the rat-feeding experiment which measured the nutritive value of the milk produced. Comment has been made in a previous paragraph on the nutritive content of the feed (10).

The blood analyses of the lactating cows, breeding efficiency, calf birth weights and growth curves of the heifers show no differences between the two groups. There was some variation in serum carotene and vitamin A within groups, but apparently no real difference of significance between the two groups. An equal number of the two breeds of cows was involved in the milk samples from the two groups. The milk production was slightly larger with the Jerseys in the unfertilized group, but this was reversed with the Holstein group (48).

The milk produced showed slight increases in percent of solids with succeeding lactation periods, but no significant differences between the groups. The amino acid distribution in the milk and colostrum proteins was the same for the two groups. The vitamin A and carotene values for both groups tended to be somewhat low, but these values as well as those for the B-vitamins were practically the same for the two groups. The cows secreted milk of practically uniform composition regardless of whether the feed came from fertilized or from unfertilized plots (11).

In the rat experiments, samples from individual cows through successive lactations and in some cases through four generations were fed. All rats received daily supplements of iron, copper and manganese. Growth was recorded, but there were no striking differences between the nutritive efficiency figures for the two groups. Analysis of variance was applied to the nutritive efficiency values obtained with milk produced by successive generations of cows. It was assumed that if the feed from depleted land had a deleterious effect, that effect would be exaggerated in succeeding generations. There was no evidence of such an effect (7).

This study therefore showed no difference in the nutritional value of milk produced by cows fed rations grown on fertilized soil when compared to unfertilized soil, but the results do suggest that land which cannot produce high quality vegetable crops can nevertheless be used for feeding dairy cattle that have the capacity for synthesizing good protein and vitamins.

GENETIC FACTORS

Genetic factors have already been shown to be responsible for marked differences in chemical composition and it would seem that improvements in the nutritive value of food plants accomplished by selective breeding are greater in magnitude than those made possible by other means.

Much progress has been made in improving the nutritive quality of fruits and vegetable foods (50). In tomatoes the ascorbic acid content has been increased to 50 mg. per 100 g., about twice that of ordinary tomatoes, and an amount approximately equal to the ascorbic acid content of citrus fruit (25). A similar long-term breeding program has been carried out for carotene in the tomato, resulting in strains in which the beta-carotene content has been increased until it approaches that of carrots (23). These are but examples. Most studies in genetic factors in vegetables and fruits have looked toward improvements in the ascorbic acid, carotene and thiamine contents. Progress is also being made in increasing the ascorbic acid in cabbage, snap beans, grapes and peaches.

In the United States new varieties of corn are being developed, and corn was the subject discussed at a recent meeting of the Agricultural Research Institute under the auspices of the National Academy of Sciences (34). As a matter of fact corn has been considerably altered down the centuries and is an excellent example of a man-developed cereal, but further progress is being made.

At the Illinois Agricultural Experiment Station, fifty generations of corn selection have produced corn with a maximum of 19.45 percent and a minimum of 4.91 percent of protein (49). Studies on this corn show that the increase of protein is accompanied by a fall in lysine and tryptophane content, similar to that noted with high-protein corn in a previous paragraph. Feeding experiments with rats likewise show a lower biological value for the protein of the high-protein corn (33). It seems that the protein in the high-protein corn also contains a high proportion of leucine, suggesting an amino acid imbalance (13). Appropriate selective breeding, however, may be able to shift the amino acid structure to one with a more favorable nutritive ratio.

The niacin content of corn has also been investigated. The relationship between pellagra and the low niacin content of corn is well-recognized. By breeding it has been possible to more than double the niacin content. This alteration in the amount of niacin has been effected quite independently of the protein fraction (38).

Wheat has in the past been bred for baking qualities. It will be interesting to observe what may now be accomplished when equivalent effort is devoted to development of the more strictly nutritional factors. A similar program on rice improvement is now under way, centered in the rice-producing countries of Southeast Asia. It is not yet clear how far this will have a salutary effect on protein nutrition in this area.

DISCUSSION

Of the factors discussed above, the focus in the past has been upon the soils factor and upon the possibility of enriching the plant through the application of appropriate fertilizer. While it appears that the composition of the plant can be slightly altered, the effects due to fertilizer are found to be generally of less magnitude than those due to other factors. Speaking in broad terms therefore there is little evidence so far that the simple addition of nutrients to the soil can be depended upon as a method for correcting dietary deficiencies in man, or, except in the matter of yield, for enhancing human nutritional health. Recent results thus tend to confirm the opinion already expressed by Maynard (30, 32).

Nutritional science, it should be noted, has already undertaken to correct threatened deficiencies in the diet by other methods, namely by food enrichment. The chemist who now produces vitamins at low cost is inclined to favor enriching white flour for example by deliberately adding thiamine, riboflavin, niacin and iron, as well as by adding vitamins A and D to milk. At present it may be simpler to add niacin to corn meal rather than to develop an agricultural product that does not need to be artificially enriched. However, in the long run the reverse may be true. The problem of the amino acids in cereal foods may soon present itself. Will it then be decided to enrich with lysine, or to look to an agricultural method to produce a cereal of higher lysine content?

While the ideal diet for most of mankind may be a combination of foods of animal and vegetable origin, emergencies may arise when we may be forced to rely on purely vegetarian products. It is appropriate therefore that the development of plant food sources which are well-balanced and complete in all the essential nutrients be pursued with vigor. The search for food materials of plant origin which can be used for infant feeding in non-milk producing areas of the world is a case in point. Much data has already been accumulated and the laboratory rat used in measuring biological values of plant protein has proved a helpful tool. In general, cereals have been found lacking in lysine and tryptophane, while legumes are richer in these two amino acids. What success has been attained has usually been concerned with vegetable mixes. While the nutritionist carries on this search, however, some continue to hope that improved food proteins of high nutritive value may still be found or developed in a single crop species which has been produced by selective breeding.

A discussion of meat production has been omitted here. The employment of the animal as a converter of agricultural product into human food has been considered elsewhere (31). The vitamin content of any given species of meat, with the possible exception of the thiamin in pork, is not seriously influenced by what the animal eats. The vitamin content of eggs and the vitamin A and carotene content of milk do vary somewhat with the character of the food intake, but there is little evidence that the protein quality of meat or meat products is influenced by the soil factor. The dairy cow furnishes a food which for any one breed appears to be remarkably constant in composition. Any variations in

chemical content of animal products are relatively small and do not represent spectacular variations in nutritive value.

While crop breeding offers improvements in nutritive value, studies on simpler life forms are also suggestive. In the laboratory the composition of chlorella has been altered so that, instead of producing carbohydrate as it normally does, it will produce considerably less carbohydrate and much more fat and protein. This type of development may be of strategic importance. Chlorella and other algae are today being proposed as new sources of food.

Still other factors that enter into the agricultural picture would include antibiotics, hormones, pesticides. These play an important role in increasing yield. How far they may influence nutritive value is still undetermined.

SUMMARY

Experimental evidence indicates that varying agricultural conditions other than climatic and genetic factors do not greatly influence the quality of the vegetable crop reckoned in terms of human nutritional effects. Programs of selective breeding have produced significant changes in the chemical composition of the plant, with in some cases proved improvement in nutritive value. It is possible that substantial improvements in the human dietary may be anticipated from developments in this direction.

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